PHOENIX LENS FOR NEUTRON AND X-RAYS

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Phoenix lens systems for generation and regeneration of arrays of refractive lenses are proposed. Arrays of refractive lenses consists of bubbles can be used for focusing X-rays and thermal neutrons. It is possible to produce 3-Darrays of refractive lenses as frozen foam of uniform bubbles. Optical properties Phoenix lens as function of type 2/3-D refractive structure and angular position are discussed.

Introduction

The experimental refractive X-ray optics starts after publication in 1996 on focusing of 18 keV X-rays by Al plate containing 30 holes in line [1]. Refractive lenses are widely used with powerful synchrotrons of the third generation: APS (USA), ERSF (France), SPring-8 (Japan). To the present moment of time number of designs of x-ray lenses are known, one of them - microcapillary refracting lens (Fig. 1) representing a glass capillary in radius 100-500 microns a containing set of 100-300 biconcave lenses developed at Belarusian State University [2].

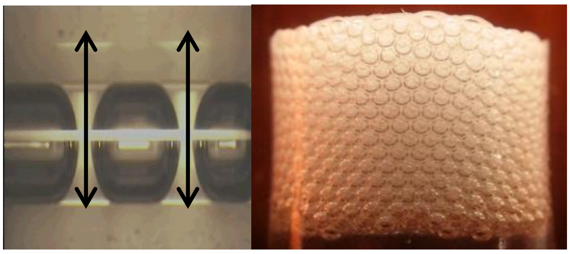

Fig. 1. Photo of microcapillary and 3-D refractive lenses.

The main directions of experimental investigation are focusing, collimating X-rays and producing enlarged X-ray images. The properties of the X-rays are similar to thermal neutrons, so refractive neutron lenses worked out on the same principles. The main idea to use refractive neutron lenses for SANS and beam diverging reduction was observed for small angle scattering experiments. Typical refractive neutron lens consists of 30 individual lenses, made from low absorbing material MgF_2, with radius 25 mm. Used in experiments refractive neutron lenses have focal distance 8.7 m and transmission 50% for 1.32 nm neutron beam, and measured gain was 9.7 [3]. As it was proposed in 1999 refractive neutron lenses can be used for new forms of neutron microscopes [4].

Main disadvantages of the refracting lenses is the small aperture of a lens, significant absorption and scattering of a beam in material, non adjustable focal distance, severe radiation load during work so radiation damages lead to small lens work time. One of the promising way is to produce 3-D structures consist of packed refractive elements: 3-D refractive lens (Belarusian state university), Clessidra, Bragg-Fresnell lenses, planar kinoform lenses, parabolic compound refractive transfocator, Alligator lens etc.

It is proposed to produce arrays of bubble lenses for focusing X-rays and thermal neutrons – “Phoenix lens”. The Phoenix lens can be made during experiment due to change optical properties or regenerate refractive lens after radiation destroying. Optical properties of Phoenix lens depends on structure of refractive arrays andangular position.

Main goal of the paper to investigate optical properties 2/3-D refractive structures for X-rays and neutrons depends on type of lens packing; produce 3-D structure and propose Phoenix lens construction.

Phoenix lens

Phoenix lens is optical set up for generation and regeneration arrays of refractive concave lenses (Fig. 2). Set up consists of: 1 – lenses shell and array of refractive lenses,2 – valve cooling liquid supply, 3 - valve air supply, 4 - cooling system, filled f.e. liquid nitrogen, 5 – valve liquid lens material supply, 6 – beam of radiation. Phoenix lens based on arrays of refractive lenses. 3-D array of refractive lenses consists of bubbles placed in transparent (glass or polymer) tube is shown in Fig. 2-4.

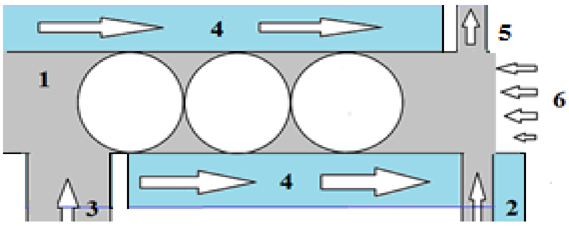

Fig. 2. Structure of Phoenix lens.

Fig. 3. Photo of 3-D lenses shell and array of refractive lenses.

Lenses shell should be transparent for visible quality control. The first stage is generation. Liquid lens material injected through 5 – valve liquid lens material supply.3 - valve air supply consists of air compressor and capillaries system for producing bubbles inside of lens material. Packed structure of bubbles is hardened by cooling system 2, 4. The second stage is using Phoenix lens with X-ray or neutron source. Structure and temperature of the array of refractive lens should be controlled. The third stage is destroying and cleaning Phoenix lens. Cooling system is stopped. Temperature of the material lens is increased to melt refractive lenses. And destroyed structure removes using valve 3, 5. After the finishing third stage regeneration or new lens production can be start.

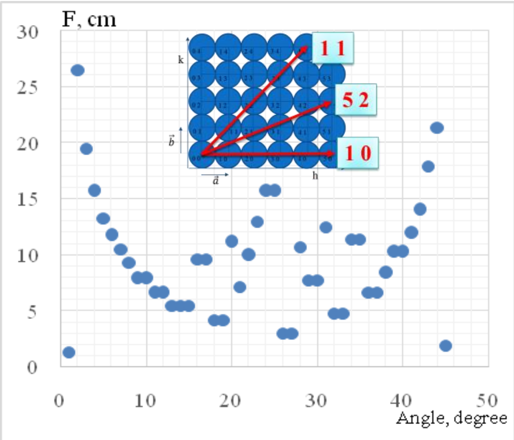

Fig. 4. Focal distance depends on angular position of planar square lattice.

Lens material should be liquid under room temperatures, with low absorption and scattering coefficients, melting point of material is less and close as possible to room temperature and far from temperature of cooling system. Experiments with water solution which melting point close to 273K (0^0C) and liquid nitrogen 77 K (-196^0C) show ability to produce hardened 3-D arrays of refractive lens Fig. 3. 3-D arrays of refractive lens made inside of glass tube with 5 mm in diameter. Number of bubbles in layer is equal to 31. Bubble (lens) diameter is 150 μm. Tube length is 10.2 cm. Number of bubble layers is 124. Number of lens for focus calculations is 62.

3-D lens structure

Real part of refraction index n is less than 1 both for X-rays and neutrons:

$$n=1-\delta+i\,(\lambda/4\pi)\mu \qquad (1)$$

Focusing X-ray and neutron lens is concave lens. Holes and bubbles in material can be used as focusing refractive lenses. Optical properties depend on type of lens structure. For description lens structure crystallography notation will be used.

In two-dimensional space 2-D, lenses (holes or bubbles) may be packed in five Brava is lattices: oblique, rectangular, centered rectangular, hexagonal (rhombic), and square. There are seven 3-D lattice systems: triclinic, monoclinic, orthorhombic, trigonal (rhombohedral), hexagonal, tetragonal, cubic. In general, the lattice systems can be characterized by the cell edges (a, b, c) and the angles between them (α, β, γ). Miller indices HKL used for description directions, planes and angular position of the 3-D lens structure.

The dependence of the optical properties of different lens structure on the direction was calculated. Developed software <2/3-D Structure Goniometer> calculate the focal length, transmission, indices HKL, the angles of rotation, the radius of the diaphragm for Phoenix lens on the base of 2-D and 3-D structures.

Results of calculations for planar square lattice, 8 keV X-rays, radius of the lens - 50 μm, the length of the structure - 5 cm, lattice period - 100 μm are shown in Fig. 4. Directions [10] and [11] has the lowest value of the focal length and the highest value of transmittance and high aperture value.

The foto of the made 3-D refractive lens shows structure of the lens is hexagonally close packed spherical bubbles. The scheme of the structure 3-D refractive lens is shown in Fig. 5. Row of the bubbles is similar to the compound refractive lens. The main geometrical parameters of the row are distance between undividual lenses L_r, thickness of the individual lens L_d, the radius of diaphragm due to the bubbles overlap R_d.

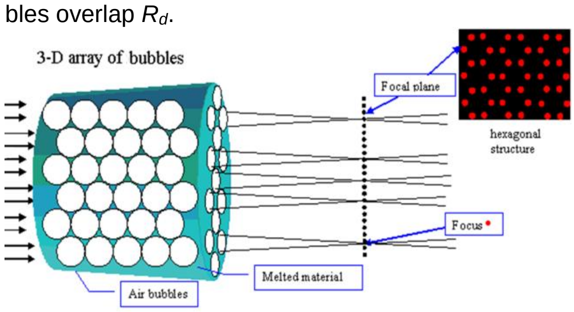

Fig. 5. The diffraction pattern resulting from auniformly – illuminated circular aperture.

Due to the hexagonal structure of the bubbles there are two types of channels inside of 3-D refractive X-ray lens. First type of channel is filled by liquid and non transparent for beam. First type of channels produce dark region in focal plane (Fig. 5). Second type of channels producered points and act like as refractive lens. The radius of the refractive lens R is equal to the radius of the bubble. From the elementary trigonometry the thickness of the lens in hexagonal structure is equal to ≈1.3R. The distance between the lenses is equal to ≈5.3R.

The radius of the diaphragm due to bubbles overlap is equal to ≈0,15R. Distance between the active channels is ≈0,58R.Focal length of the lens depends on the number of layers. The aperture of the 3-D refractive X-ray lens is the sum of the entrance areas of active red channels. Porosity factor of X-rays for this design of the 3-D refractive X-ray lens is equal to the ratio of sum active channel sizes to the total entrance area of the 3-D refractive lens. Calculated porosity factor of hexagonal close packed structure is equal to ≈10 %. This value defines flux at focal spot. Due to number of active channels Phoenix lens can produce mosaic images for visual systems or may work as multibeam scanners.

Conclusion

Phoenix lens systems for generation and regeneration of arrays of refractive lenses are proposed. 3-D arrays of refractive lenses as frozen foam of bubbles are made. Focusing properties of refractive 3-D arrays are investigated. Results of calculations optical properties Phoenix lens by developed software <2/3-D Structure Goniometer>are discussed.

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